Plants associated with wild pig (*Sus scrofa*) foraging activities in Singapore secondary forests

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Abstract

Wild pig (*Sus scrofa*) populations in Singapore have been rising over the past two decades, likely due to a lack of hunting or large natural predators to regulate their numbers, in addition to the availability of suitable habitats to expand into and possibly supplemental food from anthropogenic sources. In other nearby Asian forests, high densities of wild pigs have been shown to inhibit forest regeneration through seed predation, trampling, foraging for food (i.e., digging or rooting), creating wallows, and building birthing nests, which all may damage seedlings and saplings. Wild pigs may also facilitate the spread of invasive species by causing soil disturbances or acting as seed dispersers. Here we assessed the plants associated with pig foraging sites in Singapore along eight 6 m (W) × 1000 m (L) straight-line transects in secondary forests. In contrast to many studies elsewhere, we found that wild pig foraging sites do not appear to be associated with any specific plant group or origin status (native or non-native) within the secondary forests of Singapore. Our work is situated within secondary forests so that the knowledge gained can help inform Singapore's substantial reforestation efforts and specifically help to restore or protect habitats from wild pig degradation.

Fig. 1: A wild pig (*Sus scrofa*) in Singapore with traces of foraging (soil disturbances from rooting behaviour) in the background. Photo: B. S. Yap.

Introduction

Wild pigs (*Sus scrofa*) were extirpated from mainland Singapore in the 1950s but they have recolonised the island in the early 2000s and their range and density have since increased (Figure 1; Khoo et al., 2021; Koh et al., 2018; Yong et al., 2010; Corlett, 1992). In Southeast Asia, large wild pig populations have been shown to negatively impact forests soils, limit tree regeneration through seed predation, digging up seedlings and sapling roots, and breaking

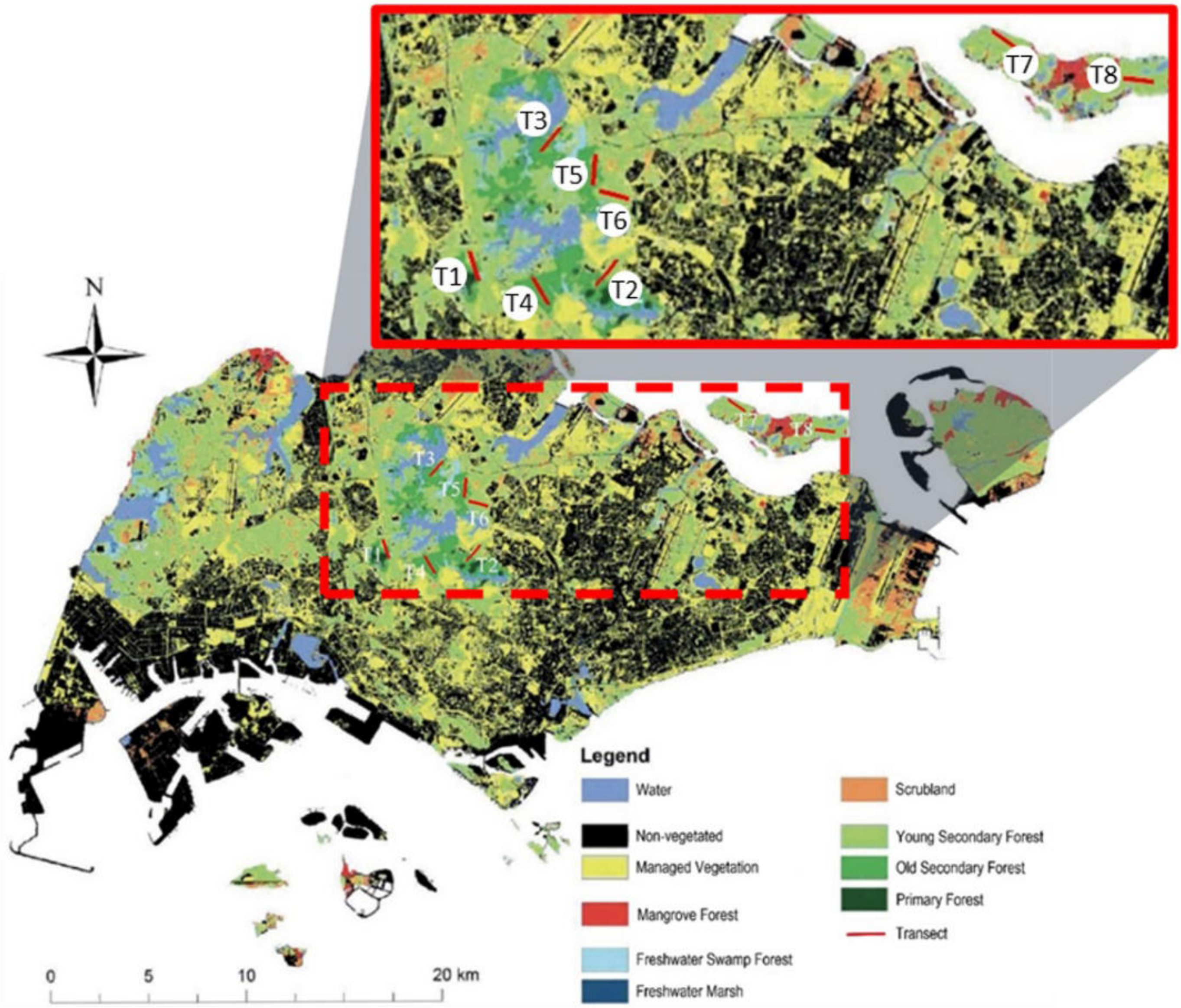

Fig. 2: Locations of eight flora and pig foraging transects surveyed across secondary forests in Singapore. Map adapted from Yee et al., 2011.

saplings to construct their birthing nests, and even reduce forest carbon storage (Luskin et al., 2021; O'Bryan et al., 2021; Williams et al., 2021; Luskin et al. 2019; Wehr et al., 2018, Luskin et al., 2017; Yong et al., 2010; Ickes et al., 2001). Furthermore, the suppression of native plant species recruitment and increased disturbance to soils, coupled with wild pigs as seed dispersers, may increase opportunities for non-native plant species to invade the forests (Wehr et al., 2018; Dovrat et al., 2012; Fujinuma and Harrison, 2012; Yong et al., 2010).

Wild pigs generally have diverse omnivorous diets including a large proportion of plant matter (Senior et al., 2016). Many studies outside of Singapore showed that wild pigs prefer certain types of plants (e.g., oak, legumes, agricultural crops), which is largely influenced by food availability, energy and nutrient content (Kim et al., 2019; Lee & Lee, 2019; Luskin et al., 2017; Rivero et al., 2017; Ballari & Barrios-García, 2014; Giménez-Anaya et al., 2008; Schley & Roper, 2003). Previous work in the nearby Pasoh forest (Pennisular Malaysia) found that wild pig habitat preferences and disturbances strongly altered tree diversity and favoured lianas over trees (Luskin et al., 2021; Luskin et al., 2019; Ickes et al., 2005). However, those studies focused on the family-level plant composition and did not investigate differences in specific plant genera or non-native versus native plant species. In this study, we investigated if particular types of plants were associated with wild pigs foraging sites in Singapore's secondary forests. Specifically, we explored whether they prefer a specific genus or genera of plants over others, and non-native over native plant species.

Our work is situated within secondary forests so that the knowledge gained can help inform Singapore's substantial reforestation efforts and specifically help to restore or protect habitats from wild pig degradation.

Methods

Study Area

Singapore comprises of 19.64% young secondary forest and 1.37% old secondary forests in terms of land area (Yee et al., 2011). It is estimated that non-native species account for 44% of the total vascular flora in Singapore, with 18% growing in the wild and 12% being regarded as fully naturalised (Nghiem et al., 2015; Chong et al., 2009).

Our work documenting the flora nearby pig foraging sites occurred in a mosaic of secondary forests (native-dominated forests and abandoned-land secondary forests) in the Bukit Timah Nature Reserve, Central Catchment Nature Reserve and Pulau Ubin island in December 2020 (Figure 2). We surveyed 2-3 randomly located 6 m (W) × 1000 m (L) straight-line transects in each of the three areas (eight in total).

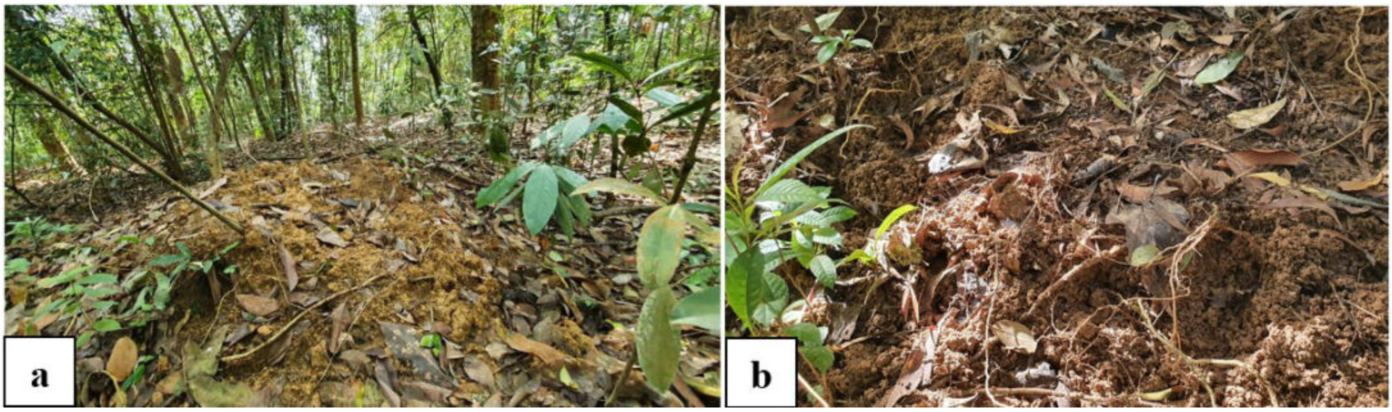

Fig. 3: Examples of a wild pig foraging sites, which are characterised by the exposed soil and roots. We assessed the plant community within a 1-m radius of foraging sites (a). Most foraging activities observed appeared to target roots (b). Photos: C. Yong.

Study species

Wild pigs (also called wild boars) are common throughout Southeast Asia. Their recent population rise in Singapore is partly due to the absence of tigers (Panthera tigris), their natural apex predator (Khoo et al., 2021; Koh et al., 2018; Yong et al., 2010). Additionally, Singapore's ban on hunting also strongly supports pig densities, similar to nearby areas of Malaysia and Indonesia where hunting is limited due of the Halal diet restrictions on pork (Luskin et al., 2014). This leaves Singapore's pig populations to be largely limited by the availability of food and suitable habitat (Khoo et al., 2021). These factors are not independent; predator loss, low hunting, and anthropogenic food subsidies act synergistically to determine pig densities. For example, the wild pig density in Southeast Asian forests that lack large predators, like Singapore, was projected to be ten times that of forests with large predators (Yong et al., 2010; Ickes et al., 2005). However, in

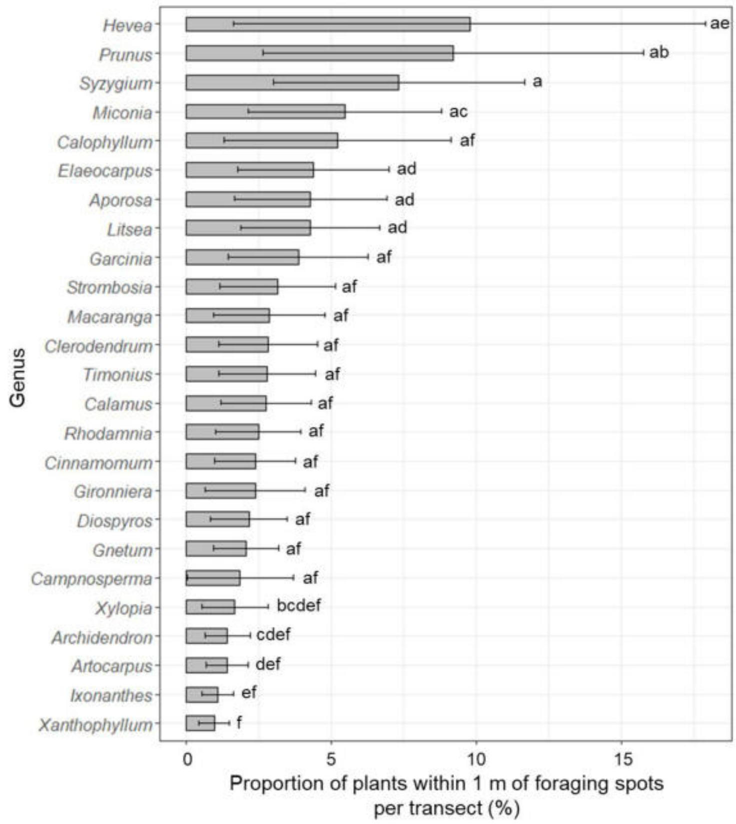

Fig. 4: Percentage of individuals of common plant genera recorded within 1-m radius of wild pig foraging sites. Bars are means and error bars represent 95% confidence intervals from a linear mixed effects model (Table 1. Different letters across genera indicate significant differences (post hoc Tukey test, P ≤ 0.05).

forests without tigers, where pig hunting is limited, and where pigs can access food subsides like crops or trash, pig densities can increase 100-fold relative to intact or hunted forests (Luskin et al., 2017). Soil disturbance by wild pig foraging behaviour is characterized by uneven surfaces of loose soil that have no litter layer or vegetation cover left from pigs turning the soil over (Figure 3). Singapore does not have any other animals that disturb the soil in this particular manner.

Flora associated with pig disturbances

We recorded all signs of foraging activity by wild pigs along randomly located 1 km straight-line transects with a 6 m wide observation window (3 m left and right). We recorded the plants within a 1 m radius of each foraging site, identified to genus and, if possible, species level. We calculated the percentage of each genus and the native versus non-native plants out of the total plant individuals per transect. We assumed that understorey plants in the pig foraging sites may have contributed towards the wild pig diet.

Statistical Analysis

We used linear mixed-effects models (LME) (Pinheiro & Bates, 2000) to compare differences in the proportion of plants near/within foraging sites among the selected common plant genera, with ‘plant genus’ treated as the fixed factor and the ‘transect location’ as a random factor. Additionally, LME models were used to compare differences in the proportion of native and non-native species found near/within foraging sites, with ‘plant origin status’ as the fixed factor and the ‘transect location’ as a random factor.

To ascertain model assumptions, standardised residuals were plotted and visually inspected. The model with the most appropriate variance structure was selected using sample-size adjusted Akaike Information Criterion values and likelihood-ratio tests (Zuur et al., 2009). Post hoc Tukey tests were conducted when the factor of interest of the selected LME model showed significant differences (Hothorn et al., 2008). All statistical analyses were conducted using ‘R’ version 4.0.5 (R Core Team, 2021) using ‘NLME’ (Pinheiro et al., 2014) and ‘MULTCOMP’ (Hothorn et al., 2008) packages.

Results

In total, 96 plant genera were recorded within 1 m of wild pig foraging sites across all eight transects. Twenty-five plant genera were recorded in at least four of the eight transects, but all 25 genera showed low occurrences (below 10% of individuals) and most showed statistically similar occurrences to each other (Figure 4; Table 1).

Native plants accounted for 89% of plant individuals (Figure 5; Table 1). The most common non-native species documented near foraging sites were hairy clidemia (*Miconia crenata*, syn. *Clidemia hirta*) and rubber (*Hevea brasiliensis*).

Tab. 1: Test statistics of one-factor linear mixed-effects models (LME) to test for the differences in percentages of plant individuals occurring near foraging sites among different common plant genera (a) and between native and non-native plants within a transect (b). Transect location was considered as a random factor for each model. Significant P values (P ≤ 0.05) are presented in bold.

	d.f. $_{(n, d)}$	F-value	P-value
(a) Proportion of common plant genera	24, 120	3.0310	**< 0.001**
(b) Proportion of native/non-native plants	1, 7	319.814	**< 0.001**

Discussion

Comparison across common plant genera

We found no patterns in plant associations with wild boar disturbances. This may differ from studies in other countries that found plant associations within wild pig diets. For example, pigs preferred oak over conifers in Korea (Lee & Lee, 2019), leguminous plants over grasses in Chile (Rivero et al., 2017), and agricultural crops (e.g., oil palm) over forest species in Malaysia (Luskin et al., 2017). The low density of energy-rich plants (e.g., legumes, oil palm) within our surveyed transects may have led pigs to to utilise all possible nearby food sources and consume readily available subsurface material.

Many of the common plant species recorded in our study are also commonly found in previous vegetation surveys of Singapore's young and old secondary forests, which can be further classified into native-dominated and abandoned-land forests (Yee et al., 2016; Chua, 2014; Neo et al., 2014). Hence, our results may be reflective of the vegetation composition of Singapore's secondary forests rather than indicative of any plant preference by the pigs. Moreover, wild pigs may have adapted to utilising energy-rich urban plants, such as yam, tapioca and oil palm, which are more abundant at the urban-forest interface outside of our study area (NSS, 2012). As such, future studies could analyse wild pig faecal samples for plant DNA composition and seed content to give a more accurate representation of what they prefer to eat, and this would serve to remove the spatial constraints of line transect sampling.

Comparison across native and non-native plants

The high occurrence of hairy clidemia near or within wild pig foraging sites could be attributed to its inherently invasive nature. Wild pig foraging activities turn over the soil, which facilitates colonisation of the site by this pioneer shrub that is known to prefer disturbed soils and canopy gaps with abundant light (Fujinuma & Harrison, 2012; Peters, 2001). On the other hand, the high occurrence of rubber plants is reflective of how it was the favoured crop for cultivation for the most recent wave of plantation agriculture (Corlett, 1992; Dobby, 1940).

Rubber plants are potentially an important supplementary food source for the wild pigs because mature trees tend to produce high numbers of seedlings and fruits (which are produced twice a year), and their shade-tolerant seedlings show high recruitment rates (Nghiem et al., 2015; Yeang, 2007). Further studies could assess if the removal of rubber trees from secondary forests can indirectly control the wild pig population. However, much care should be taken to ensure that

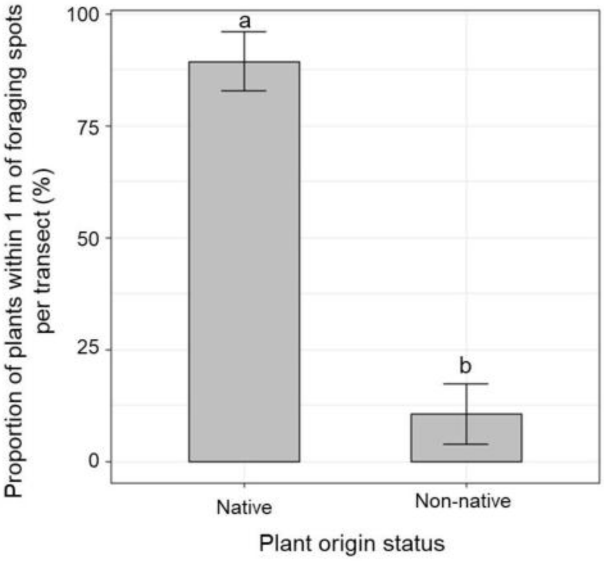

Fig. 5: Percentage of native and exotic plants recorded within 1-m radius of wild pig foraging spots. Bars are means, and error bars represent 95% confidence intervals from a linear mixed effects model. (Table 1. Different letters across genera indicate significant differences (post hoc Tukey test, P ≤ 0.05).

removal of rubber does not adversely impact other animals that also utilise this species, such as the critically endangered banded leaf monkey (*Presbytis femoralis femoralis*) (Srivathsan et al., 2016).

The non-native oil palm (*Elaeis guineensis*) has been shown to be a significant food source subsidy for wild pigs in Pasoh Forest, Malaysia (Luskin et al., 2017), but we were unable to detect this preference of wild pigs in our study. The scarcity of oil palms across our transects could be, in part, attributed to the ongoing management efforts by the local government environmental agency to remove oil palms around the island (MND, 2017).

Our findings could also be confounded by the mosaic of sub-types of secondary forests in Singapore, where some areas are native-dominated and others, such as abandoned plantation forests, show a higher proportion of non-native plant species (Yee et al., 2011, 2016). Future studies could conduct comprehensive vegetation surveys and diet analyses to determine how pigs influence plant composition of non-native species. Finally, with the lethal onslaught of African Swine Fever likely to reach Singapore in the near future, there are opportunities for natural ‘before-and-after’ studies to examine pigs influence on the environment (Luskin et al., 2020).

Conclusion

Our study provided insights into the foraging habits of wild pigs in Singapore secondary forests. Contrary to studies in other countries that indicated wild pigs show preference for certain types of plants over others, our study found that wild pigs in Singapore showed no distinct preference for any common genus or for non-native or native plants within Singapore secondary forests.

Acknowledgements

Special thanks to Nathaniel Hui for helping with fieldwork sessions. This research was supported by the National Parks Board and the CN Yang Scholars Programme – Nanyang Technological University, Singapore.

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